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SUPERCONDUCTIVITY: ACHIEVEMENTS IN APPLICATION

Abstract: A superconductor is a material that undergoes a transition into the superconducting state when cooled below a certain critical temperature. Firstly, the superconductor offers no resistance to the passage of electrical current. Secondly, external magnetic fields do not penetrate the superconductor, but remain at its surface. This phenomenon enables a range of innovative technological applications in different spheres of industry. New superconducting materials are constantly being discovered and even more new prototype devices are being developed. The recently developed prototypes based on the phenomenon of superconductivity include a three-state memory nanodevice and a terahertz emitter. The performance of these devices proves the possibility of practical applications of superconductors and stimulates future development of superconducting materials. Moreover, application of bulk superconductors is also quite promising as bulk superconductors offer a number of advantages over conventional permanent magnets. However, many problems must be solved before superconducting technology can be successfully and widely commercialized.

Keywords: superconductivity, superconductor.

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СВЕРХПРОВОДИМОСТЬ: ДОСТИЖЕНИЯ В ПРИМЕНЕНИИ

Аннотация: Сверхпроводник – это материал, который переходит в сверхпроводящее состояние при охлаждении ниже определенной критической температуры. Во-первых, сверхпроводник не оказывает сопротивления прохождению электрического тока, который может протекать без потерь энергии. Во-вторых, внешние магнитные поля не проникают в сверхпроводник, а остаются только вокруг его поверхности. Эти свойства позволяют применить сверхпроводники в различных сферах промышленности. Освоение явления сверхпроводимости может по-настоящему совершить прорыв в науке. Учёные открывают всё новые сверхпроводящие материалы и разрабатывают новые устройства. Одни из недавно разработанных прототипов устройств, основанных на явлении сверхпроводимости, включают запоминающее наноустройство с тремя устойчивыми состояниями и терагерцевый излучатель. Работоспособность этих устройств доказывает возможность практического применения сверхпроводников и стимулирует дальнейшее исследование сверхпроводящих материалов. Сверхпроводники обладают рядом преимуществ по сравнению с обычными постоянными магнитами, поэтому их практическое применение становится всё более перспективным. Однако поддержание условий для работы сверхпроводников – очень трудный и дорогостоящий процесс. Поэтому, прежде чем сверхпроводящие технологии смогут быть успешно введены в сферу промышленности, необходимо решить множество проблем и вопросов.

Ключевые слова: сверхпроводимость, сверхпроводник.

A superconductor is a material that undergoes a transition into the superconducting state when cooled below a certain critical temperature. This superconducting state is characterized by two basic properties. Firstly, the superconductor offers no resistance to the passage of electrical current. When resistance falls to zero, a current can circulate inside the material without any dissipation of energy. Secondly, external magnetic fields do not penetrate the superconductor, but remain at its surface. This field expulsion phenomenon is known as the Meissner effect.

The phenomenon of superconductivity can revolutionize modern science and electric power infrastructure. The superconductive state enables a range of innovative technological applications in different spheres of industry ranging from magnetic resonance imaging (MRI) and high-energy physics accelerators to plasma fusion reactors and magnetically levitated trains. However, despite all the advantages of superconductors, we must keep in mind the challenges that scientists have to face to properly implement any superconductive technology in real life. It is very hard and expensive to provide and support the conditions for the superconductors to work. Therefore, the main problems of application of superconducting materials include refrigeration, cost and reliability.

To properly understand all the advantages and disadvantages of superconducting materials and to find out more about current and emerging applications of superconducting technology, it is essential to study some of the recent discoveries and achievements in this field of science.

Back in 2015, some achievements were made in the field of practical application of superconducting technology. A superconducting/magnetic three-state nanodevice was developed. This fabricated device is based on the superconductivity/magnetism interplay and it benefits from the properties of ratchet effect. Ratchet effect occurs when, driven by zero-average force, particles are moving on asymmetric potentials. The developed device operates in two different working modes: without applied magnetic field and with applied magnetic field. In the first operational mode, three different outcomes emerge: positive ratchet effect, zero ratchet effect and negative ratchet effect. Therefore, the nanodevice acts as a non-volatile memory with three resilient states. In the second operational mode, the nanodevice works as a sensor for magnetic fields. Considering the importance of development of robust and versatile nanodevices with different functionalities, the developed prototype acts as a good option for a three-state memory device. Moreover, the performance of this device based on the effect of superconductivity proves the possibility of other similar useful practical applications of this technology [1].

In 2016, three prototype devices based on the recently developed terahertz (THz) emitters were developed. Terahertz waves have various unique features that open new possibilities in the research areas of science and technology that enable various important applications, such as non-destructive evaluations, various imaging techniques, high-speed communications, security, medical diagnoses, biosciences, and biotechnologies. THz emitters were based on a single-crystalline mesa structure of the high transition-temperature superconductor Bi2Sr2CaCu2O8+δ (Bi2212). The first one of the developed prototype devises is a compact and convenient THz imaging system cooled down to 40 K only by a Stirling cryocooler. The second one is a home-built Michelson type of interferometer constructed by modifying a reflection type of IJJ-THz emitter imaging system to develop a phase-sensitive imaging system. The third one is an IJJ-THz emitter device to measure the absorption coefficient of a liquid sample for temperatures between 0 °C and 70 °C. The detailed characteristics of these prototype systems and their performance prove that there is a possibility for other future applications of superconductors in similar projects [3].

In 2018, a review of current and possible future practical applications of bulk superconductors in different spheres of industry was made. Magnetized bulk superconductors are capable of acting as quasi-permanent magnets with the potential of providing magnetic fields of several tesla or greater from a small volume of material. Therefore, bulk superconductors offer a number of advantages over conventional permanent magnets. Applications of bulk superconductors include:

- Portable systems for bulk superconductivity. A portable magnet system can be considered one of the most straightforward potential applications of bulk superconductors. This system is often referred to as a trapped field magnet (TFM). This strong magnetic field is a clear advantage. However, the cost is the extra effort required in cooling and charging the system. Therefore, the key point of developing a portable magnetic system is to maximise the useable magnetic field from the bulk superconductors within a simple and user-friendly structure.
- Portable, high-field magnet systems for medical devices. High magnetic fields are used in magnetic resonance imaging. Magnetised disc-shaped bulk superconductors offer the possibility of super-strength, stable

permanent magnet (PM) analogues, capable of providing fields of several tesla in a compact and portable magnet system. The available field on the surface of such discs can be up to an order of magnitude higher than conventional PMs. Compared with electromagnets (copper-wound or superconducting), no direct, continuous connection to a power supply is required and the size of the magnet to provide the same field is considerably smaller.

- Ultra-light superconducting rotating machines for next-generation transport & power applications. Bulk superconductors can be used as trapped field magnets that could potentially provide magnetic flux densities an order of magnitude higher than conventional permanent magnets from a much smaller volume of material than wire-wound coils, without the need for continual excitation, and are therefore highly attractive for next generation electric machines.
- Magnetic shielding applications for electric machines, equipment and other high-field devices. Bulk type II superconductors have a strong ability to repel an external magnetic field, resulting in efficient magnetic «shielding» or «screening». This effect can be applied to get an ultra-low magnetic field background for ultra-sensitive devices such as superconducting quantum interference devices (SQUIDs). Moreover, this effect can be applied to protect a given volume of space placed in the vicinity of large magnetic field sources [2].

After analyzing these recent discoveries, it becomes clear that the phenomenon of superconductivity can make a big impact on science and the modern world. The development of superconducting technology can make a significant contribution to solve practical engineering challenges across a wide variety of fields. New superconducting materials are constantly being discovered and even more new prototype devices are being developed. The performance of these devices proves the possibility of practical applications of superconductors and stimulates future development of superconducting materials. However, many problems must be solved before superconducting technology can be successfully and widely commercialized. Some superconducting materials have to outperform the conventional wire technology to be of interest for applications. Therefore, scientists must focus on solving many similar problems so that superconducting technology could be properly implemented in our life.

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